now being conducted by Mr. Newbery are known. In conclusion, I beg to acknowledge my indebtedness for some points in the foregoing to a Report on the Minerals of Victoria, just completed, by Mr. G. F. Ulrich, of the Geological Survey.

Art. III.—*On the Extraction of Gold.* By Mr. H. A. Thompson.

(Read 11th September, 1866.)

The paper I have the honour to lay before the Royal Society has been compiled from my notes of experiments extending over the last six or seven years, and entered upon with a view of diminishing the heavy loss of gold now sustained in reducing quartz. The greater portion of these experiments were carried out at the works of the Port Phillip Company at Clunes by the officers of the company, or in conjunction with them, and are the more important as on that large establishment there is every facility for conducting the trials upon a working scale, while an assay office attached to the works allows of every step being tested with the accuracy which alone can make the results obtained reliable. It has long been known that a greater loss occurs in the treating of gold ores than is the case with any other metal; and although this subject has attracted the notice of scientific and practical men for many years, the advance hitherto made has hardly been commensurate with the attention bestowed upon it.

In the old gold mining works of Europe and South America the loss runs from twenty-five per cent. of the total contents of the quartz upwards, notwithstanding the accumulated experience of several generations of miners; and in California Professor Silliman reports that his examination of tailings from the different works in the Grass Valley, showed a loss of eighty dollars (say four ounces) of gold per ton, and he adds, "on the authority of one of the most cautious and experienced metallurgists of California, that the saving in a large number of cases was barely thirty per cent. of the gross contents of the ore, as determined by his own careful assays both of the ore and the waste."

In this colony assays of tailings from many different goldfields have led me to the conclusion, that the average loss sustained in crushing is not less than thirty-five per cent. of the total gold contents of the quartz, or at the lowest calculation £1,000,000 per annum. I doubt if any works are sustaining less than twenty-five per cent. loss, and several instances have come under my notice where there was a large per centage of sulphides in the quartz, and the loss of gold was in consequence from fifty to seventy per cent. of the total contents. The discovery of any method that would retain a fair proportion of the gold now lost, would add materially to the prosperity of the mining interest, but the direct saving is not all the benefit that would be obtained from it. Numerous quartz veins, now considered too poor to remunerate the miner for working them, would yield a fair profit if the gold in the sulphides were made available, as well as the free gold in the quartz, and the advantage derived from this source would be nearly as great as that accruing from the direct saving.

It has been commonly asserted that this colony was far behind other mining countries in the adaptation of improved methods for extracting the gold; but, judging from the most reliable returns we can obtain, this certainly is not the case, and either as regards the character of our machinery, or the attention given to improved methods of treating the ore, we have no reason to be ashamed of the position we hold. It should not be matter for surprise that it has taken us fifteen years to solve the problem which has baffled other gold miners for four times that period, with all the resources of an old country, cheap labour, and cheap material at their command.

For convenience the gold found in mineral veins may be divided into two classes: first, the free gold, meaning that deposited in the quartz, slate, or other matrix in a form rendering it capable of liberation by the ordinary process of crushing; and, second, the pyritous gold, meaning that deposited with and enveloped by the sulphides of iron, copper, antimony, and lead, but principally in this colony with iron.

The greater part of the free gold is deposited in particles large enough to be liberated and retained by the ordinary reducing process, but in nearly all gold-bearing quartz a certain amount of fine gold exists, which cannot be retained by the usual mode of treatment, and in some few exceptional cases the proportion of this fine gold is so considerable as to form one-third of the gold lost. This fine gold, when seen in the quartz with the aid of the microscope, presents the appearance of minute patches of gilding, and must be detached in thin flat pieces readily floated away in running water. A part may be pyritous gold liberated in the breaking up of the iron ores. In practical working some of this fine gold must always be lost, even where the greatest care is used, but a large proportion of that now carried away would be retained with the sulphides by any efficient mode concentrating the latter.

The pyritous gold is so closely incorporated with the iron and other ores, that it cannot be separated by the means found to be most economical for extracting the free gold. It has been a moot question whether this pyritous gold exists in combination with the sulphides or in a metallic state. Experiments made at Clunes, using hypo-sulphite of soda as the dissolving agent, showed a trace of other than metallic gold in rich pyrites, but none in auriferous antimony ore. In the first case the quantity was evidently so small as to be of no practical importance, nearly all the gold being mechanically deposited with the sulphides. In a sample washed from the blanket strakes, in which the grains of pyrites average about one one-thousandth of an inch in diameter, gold can be seen on the broken faces in still minuter particles, and I believe the great bulk of the pyritous gold is in this finely-divided state. Sulphides have been found in this colony containing two hundred ounces to the ton, and in New South Wales over two thousand ounces of gold per ton; but these were no doubt picked specimens, and would not represent the average yield of the sulphides in the vein. I have, however, more than half-a-ton of pyrites ready for treatment at the Good Hope mine holding nearly one hundred ounces of gold per ton; and wherever quartz veins contain a paying amount of free gold, and carry from two to five per cent. of pyrites, the latter in every case yet tried has proved to be rich in gold. I have met with no instance where the yield of the pyrites was not in proportion to the per centage of it in the quartz, and the amount of free gold that could be obtained from the ore. From ten to forty ounces of gold per ton may be taken as the average yield of the sulphides in paying quartz mines, although both higher and lower yields are occasionally met with.

But it is not the sulphides existing in the quartz veins only that are auriferous. Many of the blue slate beds, at a distance of several fathoms from the mineral veins, contain pyrites in scattered crystals studding the rock. These crystals have been collected, and on assay gave from five to fifteen dwts. of gold per ton. This fact may throw some light on the cause of quartz veins being frequently productive above and poor below the water line; a circumstance usually ascribed to the pyrites in the vein being undecomposed below the water. This is hardly sufficient to account for the sudden failure of the gold in depth in many cases, and it is possible that the existence of large quantities of undecomposed pyrites in the adjoining slate beds may have an impoverishing effect, by holding the gold and preventing its aggregation in the quartz veins.

Hitherto I have only referred to the sulphides formed in the quartz or slate; but in the old auriferous drifts of Ballarat the trunks of ancient trees are found imbedded in the gravel or drift, and on this old timber sulphides have frequently formed. A beautiful specimen of crystallized white iron pyrites deposited on a piece of wood taken from a drift immediately below the trap rock, gave by assay forty ounces of gold per ton. In another case where the old trunks were burst open, and only the sulphides formed in the heart of the tree retained, they were found to yield over thirty dwts. of gold per ton. Again, some of the fine dust obtained in washing off the gold at the Royal Saxon claim, Ballarat, yielded by assay over fifteen ozs. of gold per ton. When placed under the microscope this dust was found to be composed of minute crystals of pyrites, aggregated into round pellets, from one three-hundredth to one one-hundredth of an inch in diameter, the surface of each pellet being roughened by the projecting angles of the crystals, and unwaterworn, indicating that the formation was subsequent to the deposit of the drift. These results show that the deposition of gold along with pyrites has been in operation at a comparatively recent date and is probably still going on.

To enter into all the details of the researches made would extend this paper to too great a length, and it will be sufficient to state that careful trials, including assays of total contents, different modes of amalgamation to ascertain the amount of free gold, and microscopic examinations, indicated that the bulk of the gold lost was enveloped in the pyrites, with rare exceptions, not more than one-fourth of the loss being free gold, and this was usually small flaky pieces floated off with the water. The proportion of this free gold left in the tailings will depend on whether it has been deposited in the quartz in fine or coarse particles, and also on the more or less perfect character of the means used for retaining it. A small per centage also is left in the waste consisting of gold still attached to particles of quartz.

The plan first adopted by our miners was to roast the quartz in stacks in the open air, or in kilns, to oxidise the sulphides, and so liberate the gold, while the quartz was rendered more friable and easy to crush. After several years' trial this system was given up, as it was found to be rather injurious than otherwise. At a low heat the pyrites in the interior of the quartz was little changed, while the free gold was coated with a film of some material, probably sulphur, which impeded the action of the mercury on it. When the roasting was carried on with a higher degree of heat, the oxide of iron formed on the exposed faces of the quartz acted as a flux, and a glazed surface of slag wa formed, in which numerous minute globules of gold could be discerned under the microscope, similar to those found in the waste tailings when crushing roasted quartz. In the interior of the quartz only a portion of the sulphur was given off, while black veins were formed by the melted mono-sulphide of iron ; and other experiments led to the conclusion that a portion of the melted gold was diffused through these black veins in a form which rendered it more difficult to separate than when in its natural state. A careful experiment made on quartz roasted in a cupola furnace with a superabundance of heated air, showed that the loss of gold sustained in crushing was ten per cent. more than it would have been if the same quartz had been crushed raw. Even if the pyritous gold could have been liberated previous to crushing the quartz, it is in such a minute state of division that much of it would have been lost in the treatment found to be the most economical for extracting the free gold.

These experiments indicated that the attempt to liberate the pyritous gold by roasting the quartz before it was crushed only increased the loss, and that attention should be directed to the separation of this pyritous gold from the sand after the latter had passed the different processes used for retaining the free gold. The plan it was first proposed to carry out was to operate on the waste tailings in bulk, and as this is the principle on which the attempt at improvements are based in California and other mining countries, it may be advisable to state the reasons which induced a different line of experiment.

The first attempt to secure this gold was by means of fine grinding and amalgamating with the following results. By re-crushing the tailings with mercury in a Chilian mill about twenty-five per cent. of the gold was obtained with very careful working. In the arastra, with grooves in the bottom of the basin for mercury, the return was increased to thirty-three per cent. of the assayed contents. Several other plans based on the same principle of regrinding the sand in mercury gave similar results; and even with careful hand amalgamation, when the material operated on was clean pyrites, we could not make much improvement on the above return. Dr. Percy, of the English School of Mines, to whom this matter had been referred, states that from pyrites containing twenty-five and three-quarter ozs. of gold per ton, he only obtained eight and three-quarter ozs. when ground with mercury, but by roasting the pyrites before operating he obtained nearly twenty-five ozs. per ton. A sample of rich pyritous quartz tried by me a few months ago was ground to a fine powder and then rubbed up with mercury and hot water to extract all the free gold. The sulphides were then separated by hand washing, roasted, and amalgamated, when they yielded at the rate of one hundred and forty ozs. of gold per ton. In the two last-mentioned cases the process was conducted with a care and perfection such as could not be carried out on a large scale, and they are only quoted as a sample of numerous trials all tending to the same result, and indicating that decomposition of the pyrites was a necessary preliminary to any plan for extracting a fair proportion of the gold. But even were it otherwise, the action of the sulphur and arsenic on the mercury would prevent the sulphides from being treated in their raw state.

The advantage gained by decomposing the sulphides has long been known and acted on in working the pyritous gold veins of North and South America, where the sulphides were piled in heaps, and subjected to natural decomposition in the open air for twelve months, and then re-treated to extract the gold that had been liberated, this process being repeated several times until the gold was exhausted. But it must be evident that a plan requiring the lapse of several years before the gold in the waste can be rendered available, is not suited to the conditions under which gold mining is carried on in this colony, at the same time the expense and loss of gold attending the different re-treatments would be greater than that incurred in effecting decomposition by means of roasting.

On the other hand, the cost of roasting in bulk, in addition to that of grinding, so increased the outlay that it was only in a few cases of exceptional richness where the waste could have been so operated on profitably, and therefore little advantage would have been gained by following up this system. But as more than seventy-five per cent. of the gold lost was in the sulphides, and the greater part of the remaining gold in a form likely to be retained with them, another course was open, viz., to separate the sulphides from the comparatively worthless sand, thus reducing the bulk of the material to be acted on and the consequent expense of extracting the gold. This is the system we have been endeavouring to bring to perfection for many years, and it appears to be the only course at present known by means of which we can hope to reduce the loss of gold within reasonable bounds. As regards the larger grains of pyrites, this concentration is partially effected on the blanket strakes, and it is the sulphides obtained from them, together with a portion separated from the waste tailings, which have been operated on at the Clunes works for several years past at a cost of about £1 per ounce of gold extracted, leaving £3 per ounce for profit.

The common reverberatory furnace was first tried for roasting, but it was found to require such a large expenditure of labour and time in turning over the sand, so as to allow of every portion being exposed to the action of the heated air for a sufficient length of time to insure perfect oxidation of the sulphides as to render it a very costly process. To remedy this defect a new oxidating furnace was designed by Mr. Latta, which has been in use at the Clunes works for three years. It is a reverberatory furnace, with an inclined bed from thirty to fifty feet long, and from five to six feet wide. The bed is set at an angle that will allow the undisturbed sand to remain at rest on it, but still make it easy to rake down through doorways at the side. The sand to be roasted is fed in at the upper end of the bed, and is gradually raked down, its place being supplied by fresh charges, until it reaches the lower end of the bed completely desulphurised, and is then discharged through a narrow opening between the bed and the firebridge. This furnace may be supplied with heated air by tubes over the fire, hollow fire-bars, communicating with a hollow bridge, and, if necessary with a coil of air-pipes in the ash-pit; the object being to supply a large amount of oxygen in the heated air to combine with the sulphur and arsenic, forming sulphurous and arsenious acids, which pass off in a gaseous state, thus converting the sulphides into oxides having no deteriorating action on the mercury, and capable of ready disintegration to allow of the liberation of the gold. The sand is spread over the bed of the furnace in a thin layer, and requires about two hours' exposure to be roasted perfectly at a dull red heat. Soon as it comes out of the furnace the heated sand is quenched with water, and when cool it is ground and amalgamated in a damp state in Chilian mills, a very good system, first introduced into this colony by Mr. Hinck. About 2 cwt. of roasted sand is placed in the mill for a charge with half its weight of mercury. This is ground for half-an-hour, the mercury breaking up and becoming distributed through the sand in small globules. When it is supposed the mercury has had time to absorb the gold, water is admitted, and the globules collect together again. The sand is then flushed out and another charge placed in the mill. Some of the broken mercury escapes with the sand, and provision must be made for its separation from the waste before the latter finally passes away.

The following return gives the results obtained at the Clunes works for the first six months of the current year in operating on the pyritous sand saved from the waste in the way described before:—

Quantity of concentrated sand treated - -	183 tons
Amount of gold obtained - - - - -	539 ozs. 17 dwts.
Cost of concentrating and reducing - - -	£560
Profit on the six months' work - - - -	£1,422 5s. 8d.
Proportion of the total gold contents obtained -	87 per cent.
Loss of mercury per ton of sand treated - -	2·8 lbs.

The loss of mercury was heaviest at the beginning of the year; in the last parcel treated it was reduced to 1·6 lbs. per ton. Changes are now in contemplation intended to decrease this loss still more, and at the same time increase the per centage of gold obtained. But even in its present state this is a good practical system of treating the sulphides, giving fair returns both as regards the profit and the proportion of gold extracted; and it should be noted that this is not a mere laboratory experiment, but the results obtained in actual working on a large scale, under conditions where each step of the process is accurately tested.

The next question requiring attention was the best method of separating the sulphides from the waste tailings, and this has been found a difficult problem to solve. There is so little difference between the respective specific gravities of the quartz and iron pyrites, that the separation of one from the other in any known dressing machine, even with particles of nearly the same size, would be imperfect. But this difficulty is vastly increased through the pyrites being more friable than the quartz, and therefore broken under the stamps into much smaller particles. This difference in size counterbalances the difference in the specific gravities where water concentration only is used, thus nullifying the principle on which all the systems of ore dressing in general use are based. An attempt was made to classify the sand, but it was found that more than half the gold in the waste tailings was enclosed in particles of pyrites or sand in such a minute state of division that they could be passed through fine wire gauze having three thousand six hundred meshes to the square inch; and as it was evidently impracticable to pass one hundred tons of sand per day through sieves of this kind, the idea of direct classification was given up. A trial was made of the classifying boxes introduced by Mr. Ulrich, where the coarser sand and larger particles of pyrites pass out with the water flowing from a lower escape, and the lighter from an upper one. By this method the sand can be divided into several different qualities, but the classification is not according to size only, and is therefore imperfect. As mentioned before, the coarser particles of pyrites were retained on the blanket strakes, but the finer pieces floated away, and no dressing machine hitherto tried would retain more than a small proportion of these fine sulphides. The best result was obtained from the round concave buddle, with the improvements patented by Mr. Munday; and this machine is now being worked to advantage at Clunes and other places, but it falls far short of the requirements of the case, and the endeavour to discover a better system has, in consequence, not been relaxed.

After proving most of the known dressing machines, and many modifications of old plans, which it was hoped might overcome the difficulties in the way, without success, a trial was made of the percussion table, a dressing machine much used in Germany and South America. This is a table from ten to fourteen feet long and from four to six feet wide, slung by means of four chains leading back, and with its head resting against a block of timber. It is pushed forward by means of a lever, and when released swings back against the block with a smart blow, making from twenty to fifty blows per minute. The sand and water is run on to the head of the table and flows down it, carrying off the lighter material, the heavier being retained on the table and gradually brought up to the head by the force of the percussion blows. In dressing ordinary ores, a table of the size mentioned will put through from one to one and a half tons in twelve hours, and the material retained on it is still mixed with such a proportion of the poor waste as to require a second and sometimes a third dressing. These known defects evidently rendered the percussion table inapplicable to the concentration of the sulphides in this colony, where material and labour are so costly, however useful it may be under more favourable conditions in this respect.

The object in trying the table was therefore to see if its defects could not be remedied, or the percussion principle applied to more advantage. Careful observation of the working of a small percussion table soon led to the conclusion that the cause of its imperfect action was the hard bank formed upon it by the sand, which prevented the blow from producing its full effect on the heavier particles; and it was evident that the action would be much improved if the sand on the table could be kept loose, in a semi-fluid state, so as to allow the blow to produce a maximum effect. When finely ground ore is suspended in disturbed water, a blow given to the side of the vessel containing the mixture will momentarily check the current and tend to throw down the materials in suspension in the order of their specific gravity, the heavier particles falling first; and even where gold or any of the sulphides are in such a fine state of division as to float on the surface of the water, a similar blow will at once cause them to sink, and at the same time draw them towards the point where the blow is applied. This is the action of the percussion-table, and when the sand on the table is kept loose the sulphides, however finely crushed, are thrown down by the sudden check given to the current of water by the percussion blow, drawn below the surface of the sand on the table where they are protected from the action of the water, and gradually accumulated towards the head, the point where the blow is given. To apply this principle with success several details require to be attended to. If the sand is allowed to form a hard bank on the bed of the table the sulphides cannot settle into it; on the other hand, if the sand is kept too loose, the motion of the table forms a wave which tends to throw the sulphides to the surface, and again exposes them to the risk of being carried off by the current of water. Numerous experiments were made to ascertain the form of stirrer best calculated to meet these requirements. That finally adopted is not unlike the prong of a sluice-fork, and is made of quarter-inch nail rod iron; each stirrer being eighteen inches in length, with the end slightly curved. They are set about one and a half inch apart in rows, each row being fixed into an axle working on gudgeons nine inches above the bottom of the table, on which the curved ends of the stirrers always rest, the axles allowing each row of stirrers to rise or fall with the table. The bed of the table is covered with light boiler plate to reduce the wear, as grooves, which impede the action of the stirrers, are soon formed in a wooden bottom. The sand and water are passed over a distributing board, which delivers them in an even sheet on to the sloping head, clear of the sand on the table. The suspending chains have regulating screws on each for the purpose of adjusting the levels. The upper chains are fixed, but the lower ones pass over and are attached to a roller, by means of which the inclination of the table can be altered at pleasure without disturbing the cross levels. When put to work the table is set with a slight inclination towards the head, and is gradually lowered whenever the sand at the head collects to over two and a half inches in depth. After working for a longer or shorter time, according as the sand operated on may be poor in sulphides, or the contrary, the table will become loaded with them. The tailings should then be diverted to a spare machine, and clean water only allowed to run over the table. In a few minutes the bulk of the pyrites will have accumulated at the head, when the table must be stopped, the pyrites shovelled out, and the work resumed as before. Hitherto this machine has only been worked at the Good Hope mine; the table used there being a small one, two feet nine inches wide, with a bed seven feet long. Through this was passed the waste tailings from four head of stamps (*i.e.* from thirty-five to forty tons per week), and these were carefully sampled at short intervals before going on to the table and after leaving it, the samples being all filtered through close woven calico. The assay of these samples made at the works of the Port Phillip Company gave the following results .—

Contents of waste tailings before going on to the table - - - - -	17 dwts. 22 gr. of gold per ton.
After leaving the table - - - -	3 ,, 4 ,, ,, ,,
Amount retained on the table - -	14 ,, 18 ,, ,, ,,

Proportion of total gold contents saved, 82·3 per cent.

In the gold-bearing material saved on the table was found fine free gold, and gold still attached to particles of sand, but it principally consisted of decomposed pyrites converted by exposure in the vein above the water level into oxide of iron. It is probable that each of these particles of oxide contains a nucleous of undecomposed sulphide, yet the partial oxidation is sufficient to so reduce the specific gravity as to materially increase the difficulty of separating it from the quartz sand, and the saving of such a large proportion of this gold-bearing ore is equivalent to a saving of from ninety to ninety-five per cent. of the undecomposed sulphides. Three of these tables are now in course of erection at the Good Hope mine, and one at the Clunes, where its effective working on different kinds of material will be carefully observed, and the results laid before the Society at a future meeting.

Another important matter is the separation of the sulphides mixed with as small a proportion of waste sand as possible, but hitherto this close concentration could not be effected without such an increase of loss as more than balanced the gain through having to treat a smaller quantity of pyritous sand. With the improved percussion table a much higher degree of concentration can be effected without risk than by any other means previously discovered, and there will be a corresponding decrease in the cost per ounce of gold extracted. No doubt time and experience will lead to improvements in the working and construction of this table, but it now surmounts the difficulty which has so long stopped the way; it is simple, inexpensive, and easily erected, and when worked in conjunction with the system now in use at Clunes for extracting the gold, will retain from seventy to seventy-five per cent. of the gold at present lost in the waste tailings, at a cost not likely to exceed ten shillings per ounce obtained.